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(54) **Method for locating a radio frequency emitter**

Verfahren zum Orten eines Radiofrequenz-Senders

Procédé pour déterminer la position d'un émetteur à fréquence radio

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- **PATENT ABSTRACTS OF JAPAN vol. 13, no. 1 (P-808)6 January 1989 & JP-A-63 210 793 (MITSUBISHI CO.)**

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Description

This invention relates to a method for locating a radio frequency emitter that transmits pulses in a swept beam pattern.

In electronic warfare applications, the need arises to locate a radio frequency emitter that transmits pulses in a swept beam. Such a swept beam is usually produced by a rotating antenna, but could also be produced by an oscillating antenna. Current techniques for locating such an emitter require that the observation point lies in the line of sight of the emitter. This requirement means that an emitter can only be located when the observation point is exposed to attack from the emitter. The accuracy of some current techniques for locating a radio frequency emitter also depends upon precise angle measurements, which may be difficult to obtain.

Such a technique is disclosed in document US-A-4,438,439. With the known method the observation point has to be in a direct line of sight from the emitter. At the observation point the times of arrival of a plurality of terrain point reflections of a single pulse transmitted by the emitter are measured and the measuring step is repeated for a plurality of pulses transmitted by the emitter. Based on the travelling times of the pulses from the emitter either directly or via reflection from the terrain points to the observation point in connection with precise angle measurements of angles between the emitter and the different terrain points as seen from the observation point the location of the emitter is calculated.

A similar technique is disclosed in document US-A-4,386,355. In order to improve the angular resolution according to that known method a terrain map is calculated from the either directly or via reflection from terrain points received pulses. The actual position of the observation point is calculated by comparing the thus produced map with a map stored in a memory of the system. This method also requires that the observation points have to be in a direct line of sight from the emitter.

In view of this prior art it is an object of the present invention to provide a method of the kind mentioned above which eliminates the deficiencies of the prior art.

According to the method mentioned at the outset this object is achieved by the steps of:

- storing intervisibility data of terrain points in a region around an observation point that does not have to be in direct line of sight from the emitter;
- measuring at the observation point the times of arrival of a plurality of terrain point reflections of a single pulse transmitted by the emitter;
- repeating the measuring step for a plurality of pulses transmitted by the emitter; and
- comparing terrain points of reflection calculated from the measured times of arrival for assumed emitter locations with the stored intervisibility data of terrain points.

The invention is thus a method for locating a radio frequency emitter at an observation point that does not have to be in a direct line of sight from the emitter by using terrain intervisibility data and the relative times of arrival of signals from a single pulse reflected from different points on the terrain at the observation point. The emitter transmits pulses in a regular swept beam pattern. As a result of this regular pattern, the angles of transmission of the pulses can be inferred. Intervisibility data of terrain points in a region around the observation point are stored in computer memory. At the observation point, measurements are made of the times of arrival of a plurality of terrain point reflections of a single pulse transmitted by the emitter. These measurements are repeated for a plurality of pulses transmitted by the emitter. In a computer, a comparison is made of the terrain points of reflection calculated from the measured times of arrival for candidate, i.e., assumed emitter locations with the stored intervisibility data of terrain points. Precise angle measurements are not required to locate a radio frequency emitter in this way.

The features of a specific embodiment of the best mode contemplated of carrying out the invention are illustrated in the drawings, in which:

FIGS. 1 to 3 are diagrams illustrating spatial considerations used to explain the invention;

FIGS. 4 and 5 are waveforms illustrating time relationships used to explain the invention;

FIG. 6 is a schematic block diagram of apparatus for practicing the invention;

FIG. 7 is a schematic block diagram that illustrates the data used by a computer to locate an emitter in accordance with the principles of the invention; and

FIGS. 8A, 8B, 8C and 8D are diagrams representing the feasibility of various emitter locations.

FIG. 1 is a schematic plan view of a terrain based emitter 10 to be located relative to an observation point 12. It is assumed that emitter 10 rotates at a constant angular velocity of 30° per second and transmits pulsed radio frequency waves, e.g., at 1.344 gigahertz, with a pulse repetition rate, e.g., of 450 pulses per second. It is also assumed that emitter 10 has a directional radiation pattern with a narrow main beam or lobe, e.g., 2° to 3°, and lower intensity side lobes. It is further assumed that the altitude of emitter 10 and observation point 12 and the terrain altitude therebetween is such that observation point 12 is not in a direct line of sight from emitter 10, i.e., observation point 12 is below the line of sight of emitter 10.

Observation point 12 could be a low flying aircraft, a ground site, or a ship on water. When the main beam of emitter 10 is not directed at observation point 12, some

of the radio frequency energy from the side lobes reaches observation point 12 through ground reflections in a direct line, path as depicted by the broken line in FIG. 1. Some of the radio frequency energy from the main beam also reaches observation point 12 after lateral reflection from terrain points, such as a point 14, as depicted by the unbroken line in FIG. 1. Thus, each pulse transmitted by emitter 10 reaches observation point 12 in the direct line path and thereafter reaches observation point 12 from a number of laterally reflective paths via various terrain points such as point 14. The time delays between the direct line pulse and the reflected pulses received at observation point 12 are indicative of the specific terrain points from which the delayed pulses are reflected. The longer the transmission path from emitter 10 to the terrain point of reflection and from there to observation point 12, the longer the time delay.

By analyzing the radio frequency energy received at observation point 12 from emitter 10, the angular velocity at which emitter 10 rotates, its pulse repetition rate, and its direction from observation point 12 as a function of time can be determined. Specifically, an extraordinarily large radio frequency energy pulse, hereafter called Peak of Beam (POB), is received at observation point 12 when the main beam of emitter 10 transmits in a direct line to observation point 12. Treating this direct line, i.e., the broken line in FIG. 1, as the angular reference for rotation of emitter 10, the approximate angular position of the main beam of emitter 10 at the time of reception of each direct line pulse at observation point 12 can be inferred. This pulse is, in general, detectable even though the observer does not have direct line of sight to the emitter. Thus, assuming counterclockwise rotation of emitter 10, after 675 pulses from POB, emitter 10 is at an angle of 45° and after 1350 pulses from POB, emitter 10 is at an angle of 90°.

In FIG. 2, point O represents observation point 12 and points E_1 and E_2 represent two emitter locations in the same direction from observation point 12 in a rectangular coordinate system having an I axis and a J axis. The coordinate system is defined so point O is at the origin and points E_1 and E_2 are on the J axis. A given pulse transmitted when the main beam is at an angle θ and arriving at point O after a specified time delay would be reflected from a terrain point F_1 if emitter 10 were located at point E_1 and would be reflected from a terrain point F_2 if emitter 10 were located at point E_2. Thus, for a particular angle θ, and a specified time delay, there is a locus of possible terrain points, represented as a line 16 corresponding to the possible emitter locations. For the particular angle θ and time delays there are different loci of terrain points, shifting downward and to the right in FIG. 2 with increasing time delay.

In FIG. 3, a single emitter location E is assumed. The distance between points E and O, which defines the emitter location relative to observation point 12, is represented by a distance r. θ is the angle of the main beam at the time of pulse transmission, I is one coordinate of a terrain point of reflection, and J is the other coordinate of the same terrain point of reflection. For a specific location of emitter 10, i.e., point E, and a variable angle θ, the locus of possible terrain points from which a reflected pulse could reach observation point 12, after a given time delay relative to a directly transmitted pulse is defined by an ellipse, as illustrated in FIG. 2, because the reflected transmission paths for all such terrain paths are the same. Thus, the delayed pulses received at observation point 12 correspond to ellipses increasing in size about points O and E with increasing time delay. This relationship is expressed by the equation:

$$\frac{4(Y-r/2)^2}{(r+D)^2} + \frac{4X^2}{(r+D)^2-r^2} = 1 \qquad (1)$$

where the difference between each reflected transmission path, i.e., the sum of the distance from point E to a point (I, J) and the distance from such point (I, J) to point O, and the direct transmission path r equals D. The pulse time delay, τ, equals D divided by the speed of light.

Furthermore, since the distance r equals the sum of the distance from point O to point (I, J) J and the distance from point J to point E, the relationship among I, J, r and θ can be expressed by the following equation:

$$Y=r-X\cot\theta \qquad (2)$$

From equations (1) and (2), the coordinates of a point of reflection can be expressed in terms of the distance r, the angle of the main beam θ, and D, the difference between the reflected and direct transmission paths from point E to point O as follows:

$$X=\frac{(r+D/2)\sin\theta}{1+r/D\ (1-\cos\theta)} \qquad (3)$$

$$Y=r-\frac{(r+D/2)\cos\theta}{1+r/D\ (1-\cos\theta)} \qquad (4)$$

The additional information about emitter location that can be obtained from delays due to terrain reflections for successive pulses from the emitter at the assumed pulse repetition rate is not significant. Therefore, only a fraction of the pulses transmitted by the emitter are ordinarily processed in the practice of the invention. By way of example, every 30th pulse transmitted by the emitter could be processed. Thus, for every 2° rotation of θ, a set of time delay-data is collected.

FIG. 4 represents the directly transmitted pulses from the emitter received at the observation point. Large pulses 18 represent the POB pulses transmitted at twelve second intervals. Pulses 20 represent the pulses directly transmitted at successive angular positions of the emitter between the POB pulses. For the assumed emitter characteristics, 5,400 pulses 20 appear between successive pulses 18. Each 30th pulse 20 is processed to derive information about the emitter location during a sampling interval T, e.g., 600 microseconds, which is less than the period between pulses 20.

FIG. 5 represents the radio frequency energy from a single pulse received at the observation point from the emitter. Pulse 20, as before, is the directly transmitted pulse. Pulses 22, 24 and 26 are reflections from terrain

points in the region around the observation point. A broken horizontal line 28 represents the threshold for discriminating between reflected pulses and noise. The time delay between pulses 20 and 22 is represented as τ_1. The time delay between pulses 20 and 24 is represented as τ_2. The time delay between pulses 20 and 26 is represented as τ_3. Delays τ_1, τ_2, and τ_3 are proportional to the transmission paths from the emitter to the observation points via the terrain points of reflection minus the direct transmission paths from the emitter to the observation point, i.e., $\underline{r}$.

FIG. 6 illustrates apparatus for collecting and processing the pulses from the emitter at the observation point. The radio frequency energy is intercepted by an antenna 30 and fed to a receiver 32, which converts the radio frequency energy to intermediate frequency. A Peak of Beam (POB) detector 34 controls a transmission gate 36. With reference to FIG. 4, detector 34 opens gate 36 for the interval between two successive POB pulses 18, during which a total of 5,400 directly transmitted pulses pass from receiver 32 through gate 36 to a transmission gate 38. These pulses are sensed by a direct pulse detector 40 and applied to a counter 42. After every 30th pulse, counter 42 opens gate 38 for a sampling interval T. The resulting sample as represented in FIG. 5 is coupled to an analog to digital (A/D) converter 44, which digitizes a large number of samples, e.g., 3,000 samples at sampling intervals of 0.2 microsecond. The digitized samples are collected in a buffer storage device 46. After all the samples have been digitized they are transferred en masse to the memory of computer 48.

The emitter is located by comparing the time delays of the reflected pulses with intervisibility data stored in the memory of computer 48. For each terrain point (I, J) in the region around the observation point there are stored in the memory of computer 48 a value of masking depth, $\bar{\bar{Z}}$, i.e., the height above the terrain point that is visible from the observation point.

A method for determining such intervisibility data is described in the co-pending European Application EP-A-0 337 338, filed on April 8 , 1989, by R. E. Huss and R. M. Denlinger. Computer 48 compares terrain points of reflection (I, J) calculated from the measured times of arrival of a pulse transmitted by the emitter using equations (3) and (4) for candidate, i.e., assumed emitter locations, $\underline{r}$, with the stored intervisibility data of terrain points (I, J). From this comparison, emitter locations corresponding to some terrain points (I, J) can be eliminated from consideration for the location of the emitter, because of the intervisibility data at such terrain points. For example, the masking depth at a particular terrain point might be so high that a reflection from such terrain point to the observation point would be virtually impossible.

Alternatively, the masking depth at a particular terrain point might be near zero or the terrain point may be visible from the observation point so that a pulse transmitted from an assumed emitter location could have been reflected from that terrain point with the time delay, τ, of the signal received at the observation point; such an assumed emitter location is a good candidate for acceptance as the actual emitter location. By utilizing, in addition, other data about the terrain points such as reflectivity, intervisibility data between the terrain point and the assumed emitter location, and measured time delay data to other observation points, the evaluation of possible emitter locations, vis-a-vis the terrain points in the region around the observation point, can be further refined.

The process is depicted functionally in FIG. 7. Intervisibility data represented by a block 50, namely I, J, and $\bar{\bar{Z}}$, and reflected signal data represented by a block 52, namely D and θ are evaluated, as represented by a block 54. The result of this evaluation provides a feasibility of candidate emitter locations at the terrain points in the region about the observation point, as represented by a block 56. As represented by a block 58, other data can also be evaluated to refine the feasibility indication.

FIGS. 8A to 8D represent plots of feasibility of various emitter locations. The feasibility (F) is indicated on the vertical axis, and the terrain points of candidate emitter locations from the observation point (O) are indicated on the J and I axes. The feasibility (F) for each terrain point is determined by counting the number of reflections received at the observation point that could have been transmitted from each terrain point, assuming that it was the emitter location, based on the comparison of time delays of reflected pulses with intervisibility data. The highest value of feasibility (F) occurs at the likely emitter location (E). Thus, FIGS. 8A to 8D depict a scoring function of the possible emitter locations based on the described comparison of the time delays of the reflected pulses with the intervisibility data. Different measures of scoring, i.e., evaluating these comparisons, could be employed to further refine the feasibility data.

Claims

1. A method for locating a radio frequency emitter (10) that transmits pulses (18, 20) in a swept beam pattern, comprising the steps of:

   - storing intervisibility data (50) of terrain points (14) in a region around an observation point (12) that does not have to be in a direct line of sight from the emitter (10);

   - measuring at the observation point (12) the times of arrival (τ) of a plurality of terrain point (14) reflections (52) of a single pulse (18, 20) transmitted by the emitter (10);

   - repeating the measuring step for a plurality of pulses (18, 20) transmitted by the emitter (10); and

- comparing terrain points (14) of reflection calculated from the measured times of arrival (τ) for assumed emitter (10) locations with the stored intervisibility data (50) of terrain points (14).

2. The method of claim 1, characterized in that the measuring step comprises measuring the times of arrival (τ) of the plurality of terrain point (14) reflections (52) relative to the time of arrival (τ) of the single pulse (18, 20) directly from the emitter (10).

3. The method of claim 1 or 2, characterized in that the repeating step measures a fraction of the pulses (18, 20) transmitted by the emitter (10).

4. The method of any of claims 1 through 3, characterized by the steps of storing reflectivity data of terrain points (14) in the region and comparing the terrain points (14) of reflection calculated from the measured times of arrival (τ) for assumed emitter (10) locations with the stored reflectivity data of terrain points (14).

Patentansprüche

1. Verfahren zum Lokalisieren eines Hochfrequenzsenders (10), der Pulse (18, 20) in einem geschwenkten Strahlungskeulenmuster aussendet, mit den Schritten:

- Speichern von die gegenseitige Sichtbarkeit betreffende Daten (50) von Geländepunkten (14) in einem Gebiet um einen Beobachtungspunkt (12) herum, der sich nicht in einer direkten Sichtlinie zu dem Sender (10) befinden muß,

- Messen der Ankunfszeiten (τ) von einer Vielzahl von an Geländepunkten (14) erfolgenden Reflexionen (52) eines von dem Sender (10) übertragenen einzelnen Pulses (18, 20), wobei diese Ankunftszeiten an dem Beobachtungspunkt (12) gemessen werden,

- Wiederholen des Meßschrittes für eine Vielzahl von von dem Sender (10) übertragenen Pulsen (18, 20), und

- Vergleichen von aus den gemessenen Ankunftszeiten (τ) für angenommene Senderorte (10) berechneten Reflexions-Geländepunkten (14) mit den gespeicherten, die gegenseitige Sichtbarkeit betreffenden Daten (50) vom Geländepunkten (14).

2. Verfahren nach Anspruch 1, dadurch gekennzeichnet, daß der Meßschritt das Messen von Ankunftszeiten (τ) von der Vielzahl von an Geländepunkten (14) erfolgenden Reflexionen (52) relativ zu der Ankunftszeit (τ) des einzelnen Pulses (18, 20) direkt von dem Sender (10) umfaßt.

3. Verfahren nach Anspruch 1 oder 2, dadurch gekennzeichnet, daß der Wiederholungsschritt einen Teil der von dem Sender (10) ausgesendeten Pulse (18, 20) mißt.

4. Verfahren nach einem der Ansprüche 1 bis 3, gekennzeichnet durch die Schritte des Speicherns von Reflektivitätsdaten von Geländepunkten (14) in dem Gebiet und des Vergleichens der Reflexions-Geländepunkte (14), die aus den gemessenen Ankunftszeiten (τ) für angenommene Senderorte (10) berechnet werden, mit den gespeicherten Reflektivitätsdaten von Geländepunkten (14).

Revendications

1. Procédé pour localiser un émetteur (10) radiofréquence qui émet des impulsions (18, 20) suivant un diagramme de rayonnement balayé, comprenant les étapes qui consistent:

- à stocker des données (50) d'intervisibilité de points (14) de terrain dans une région entourant un point (12) d'observation qui n'a pas à être en visibilité directe de l'émetteur (10);

- à mesurer, au point (12) d'observation, les temps d'arrivée (τ) d'un ensemble de réflexions (52) d'une impulsion (18, 20) unique émise par l'émetteur (10) par des points (14) de terrain;

- à répéter l'étape de mesure pour un ensemble d'impulsions (18, 20) émises par l'émetteur (10); et

- à comparer des points (14) de terrain de réflexion calculés à partir des temps d'arrivée (τ) mesurés pour des positions supposées de l'émetteur (10) avec les données (50) d'inter-visibilité stockées de points (14) de terrain.

2. Procédé selon la revendication 1, caractérisé en ce que l'étape de mesure comprend la mesure des temps d'arrivée (τ) de l'ensemble de réflexions (52) des points (14) de terrain par rapport au temps d'arrivée (τ) de l'impulsion (18, 20) unique provenant directement de l'émetteur (10).

3. Procédé selon la revendication 1 ou 2, caractérisé en ce que l'étape de répétition consiste à mesurer une fraction des impulsions (18, 20) émises par l'émetteur (10).

4. Procédé selon l'une quelconque des revendications 1 à 3, caractérisé par les étapes qui consistent à stocker des données de réflectivité de points (14) de terrain dans la région considérée et à comparer les points (14) de terrain de réflexion calculés à partir des temps d'arrivée mesurés (τ) pour des positions supposées de l'émetteur (10) en utilisant les données stockées de réflectivité de points (14) de terrain.

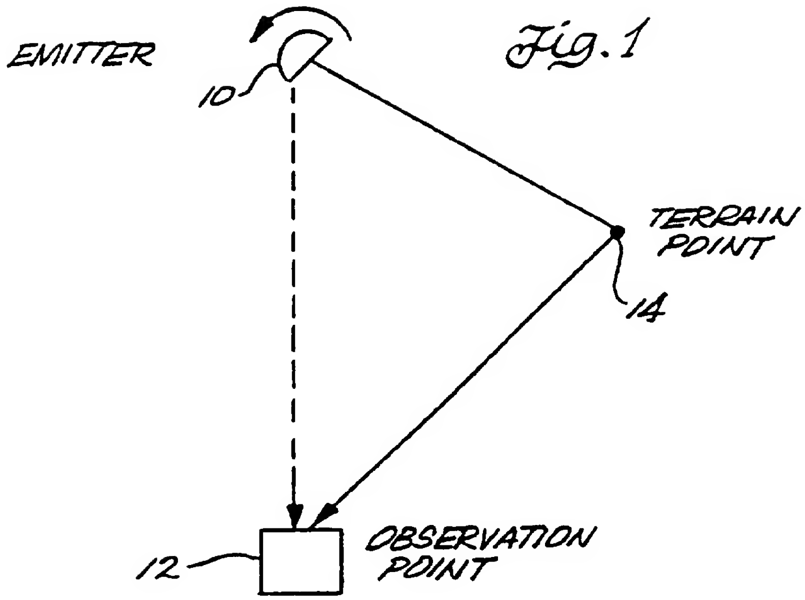


Fig. 1

Fig. 2

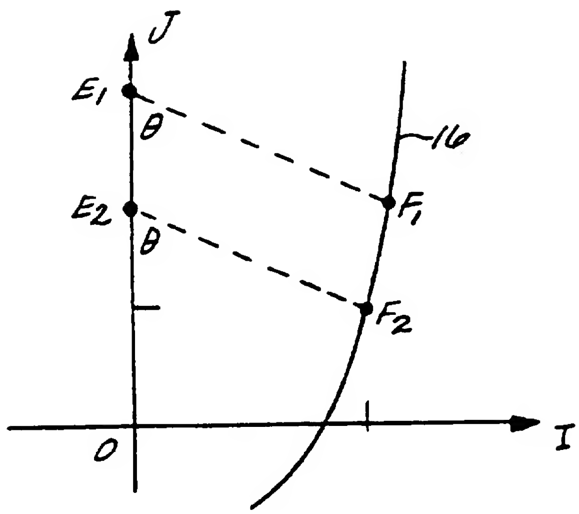
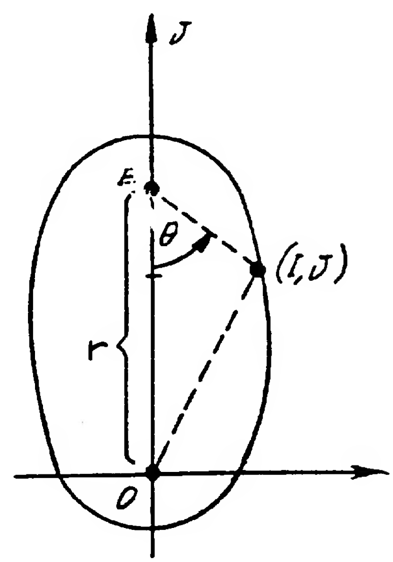


Fig. 3



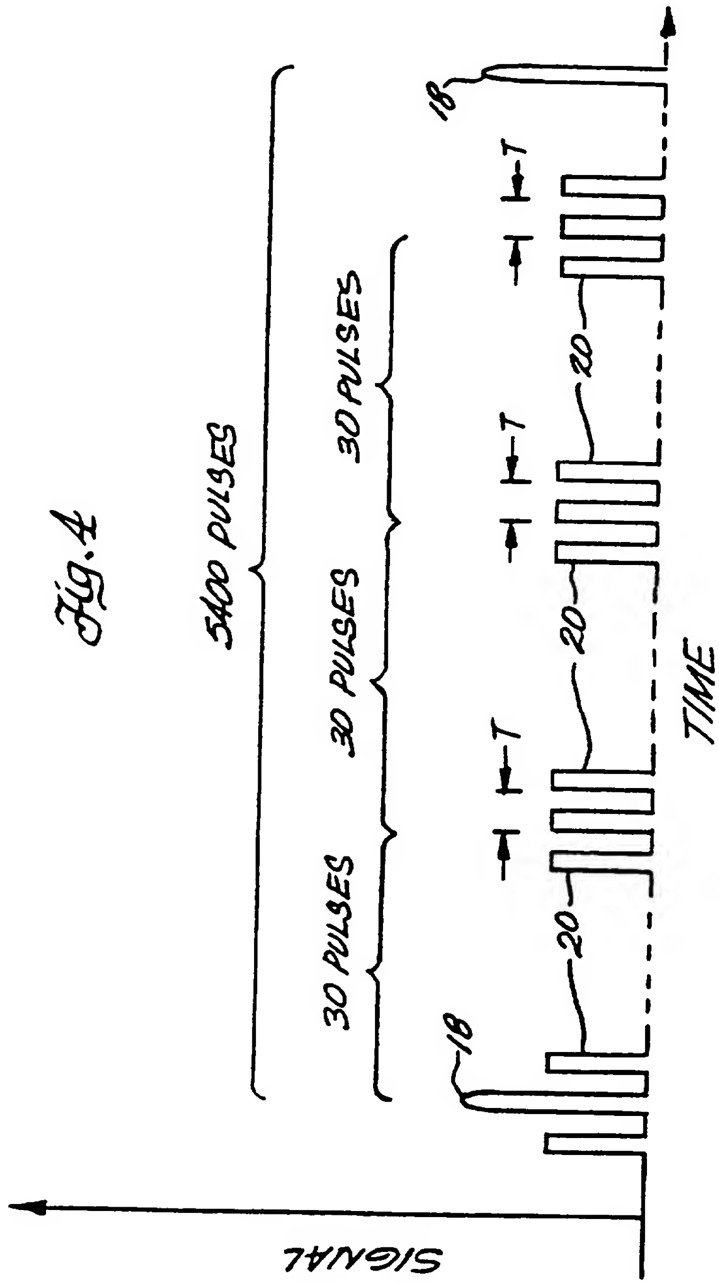


Fig. 4

Fig 5

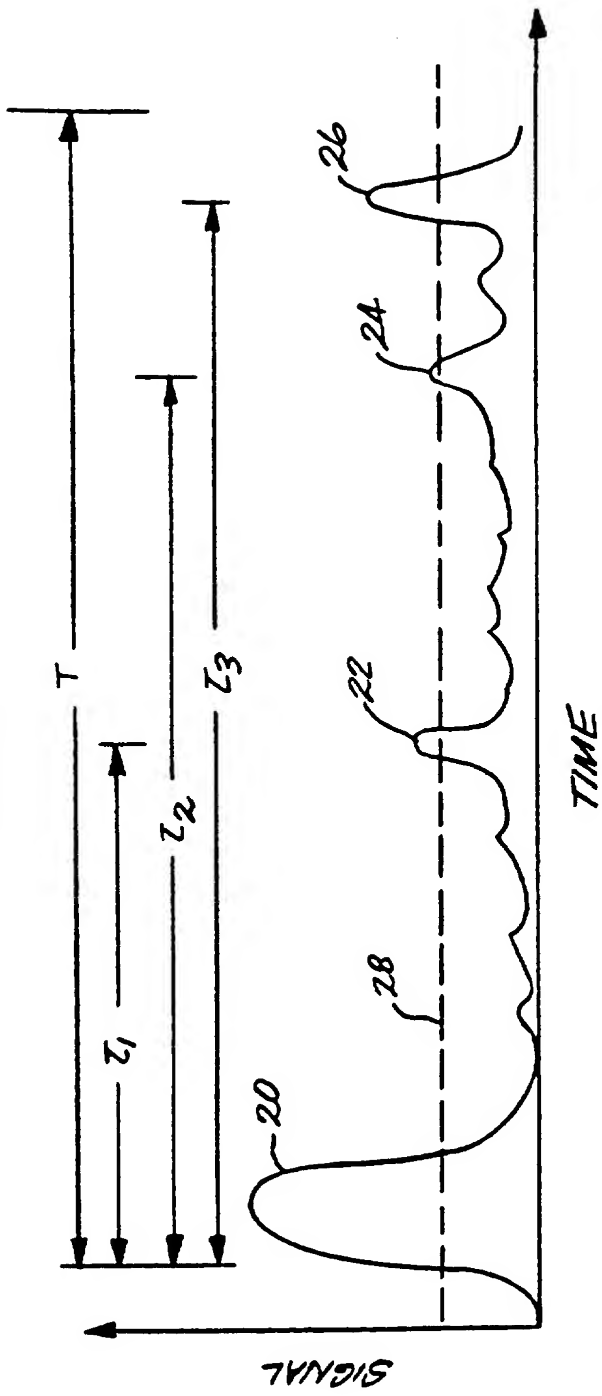
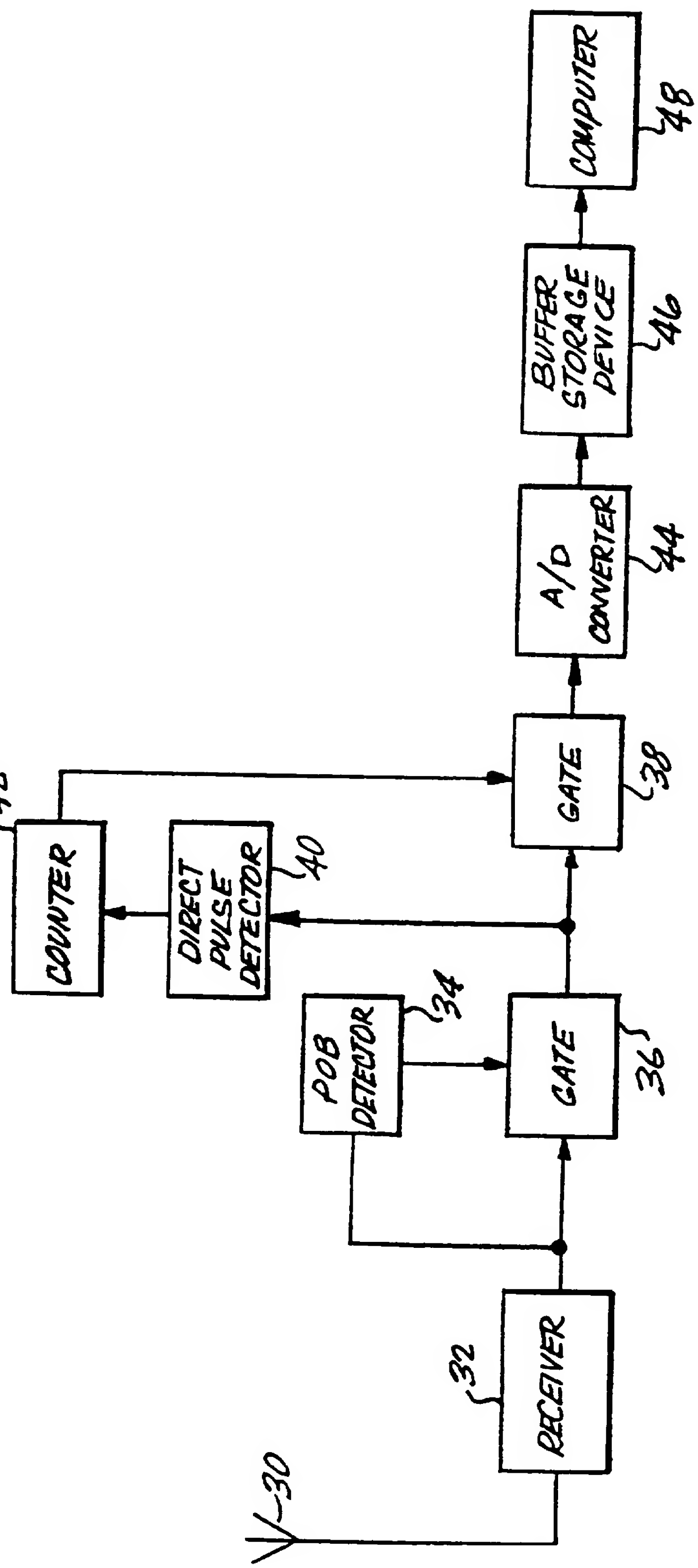


Fig.6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RECEIVER
32
POB DETECTOR
34
GATE
36
DIRECT PULSE DETECTOR
40
COUNTER
42
GATE
38
A/D CONVERTER
44
BUFFER STORAGE DEVICE
46
COMPUTER
48

Fig. 7

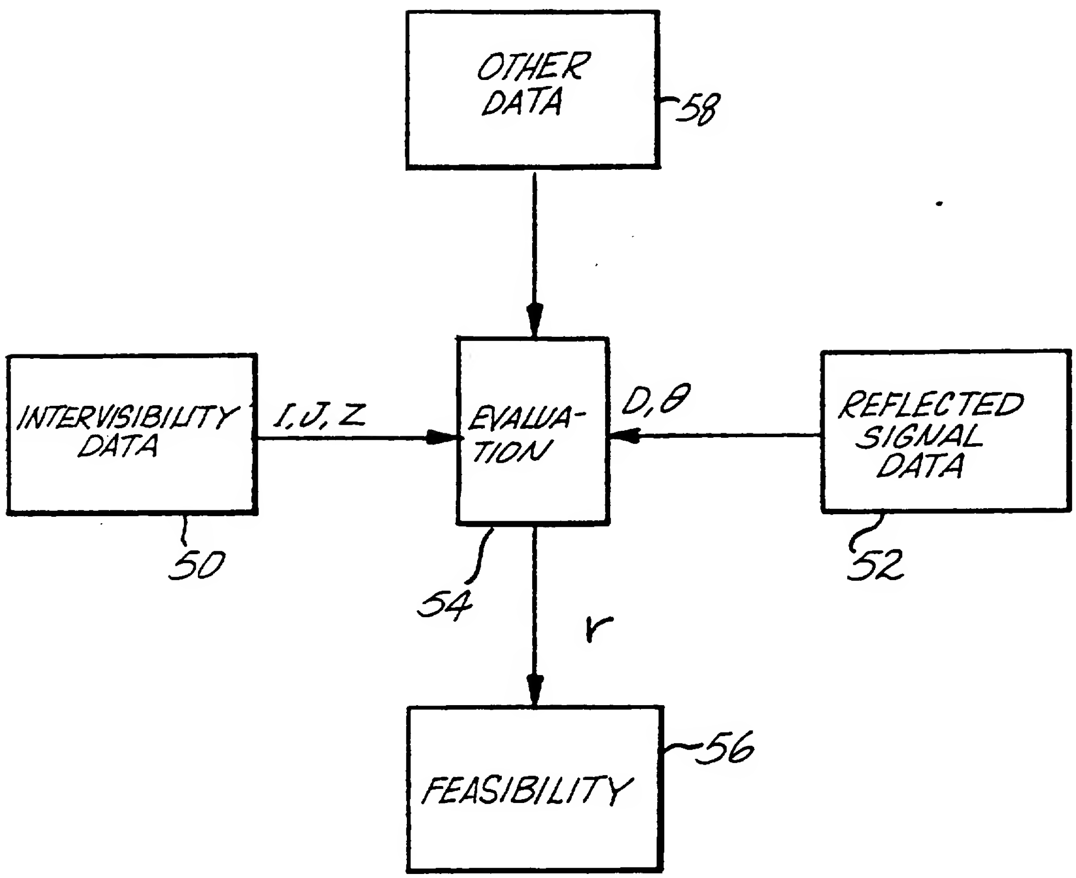
OTHER DATA
58
INTERVISIBILITY DATA
I, J, Z
EVALUATION
D, θ
REFLECTED SIGNAL DATA
50
54
52
r
FEASIBILITY
56

Fig. 8A

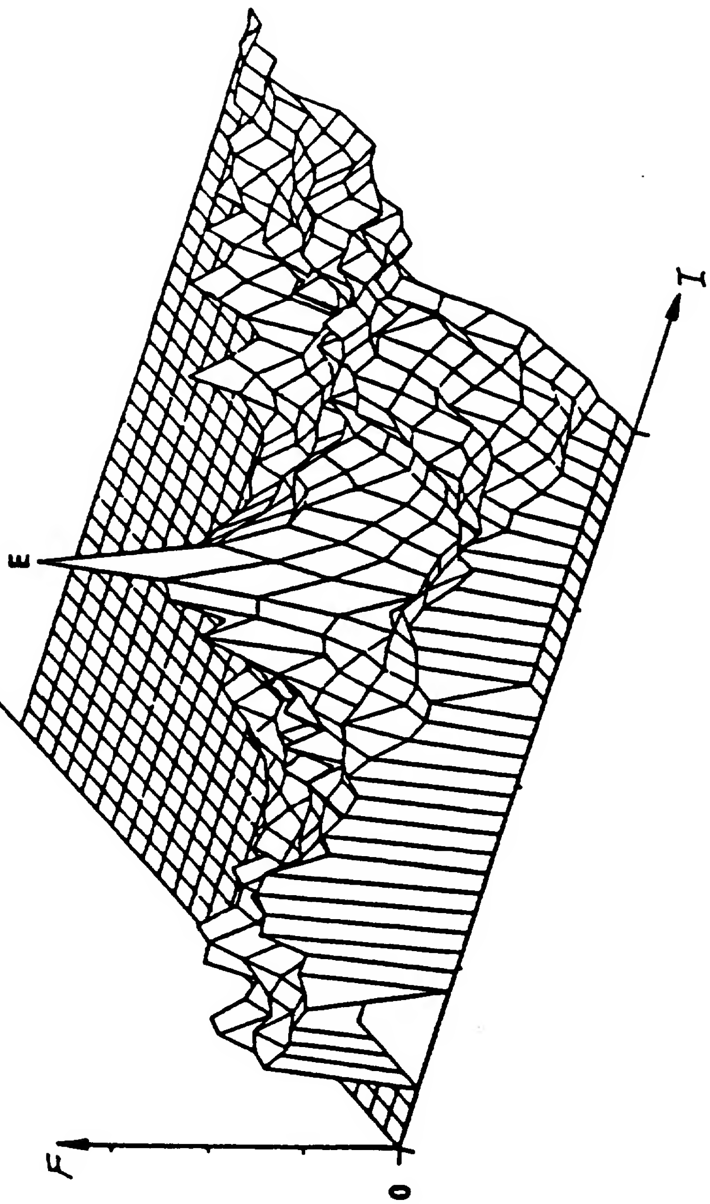

Fig.8B

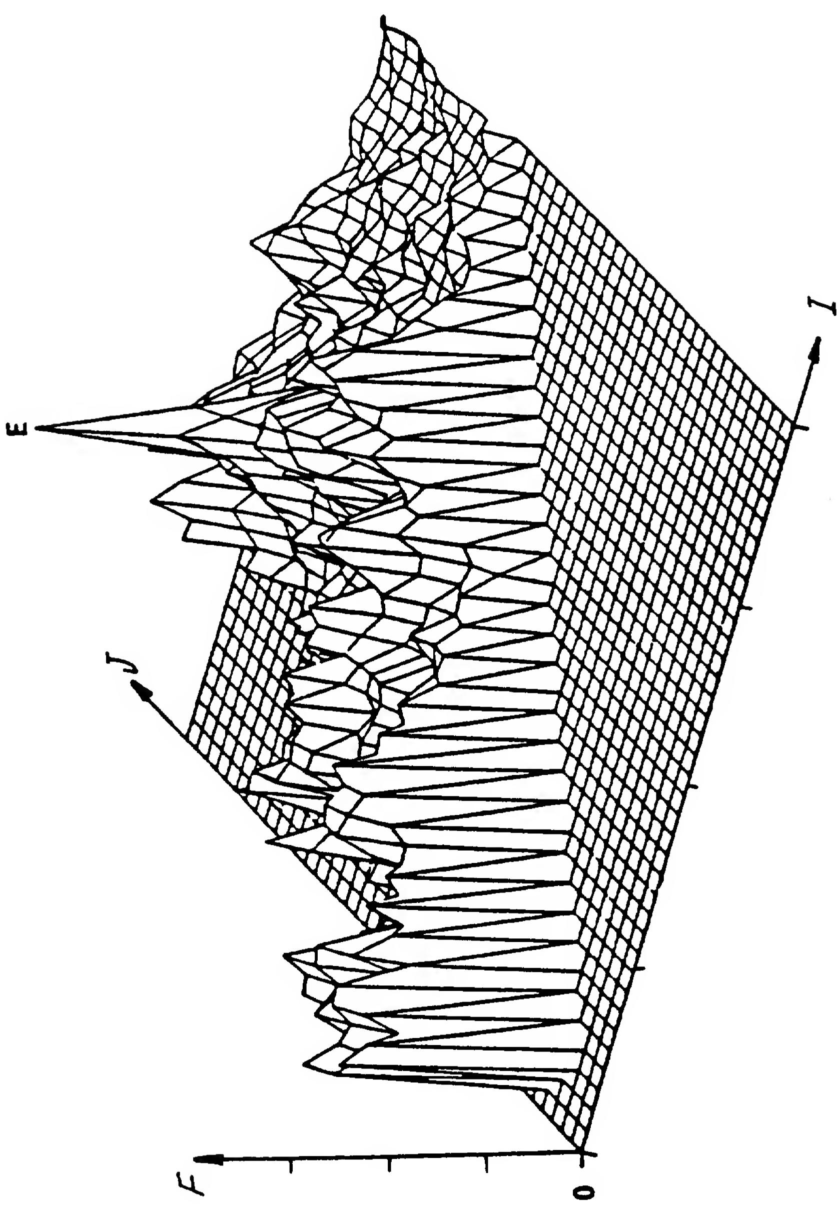

Fig. 8C

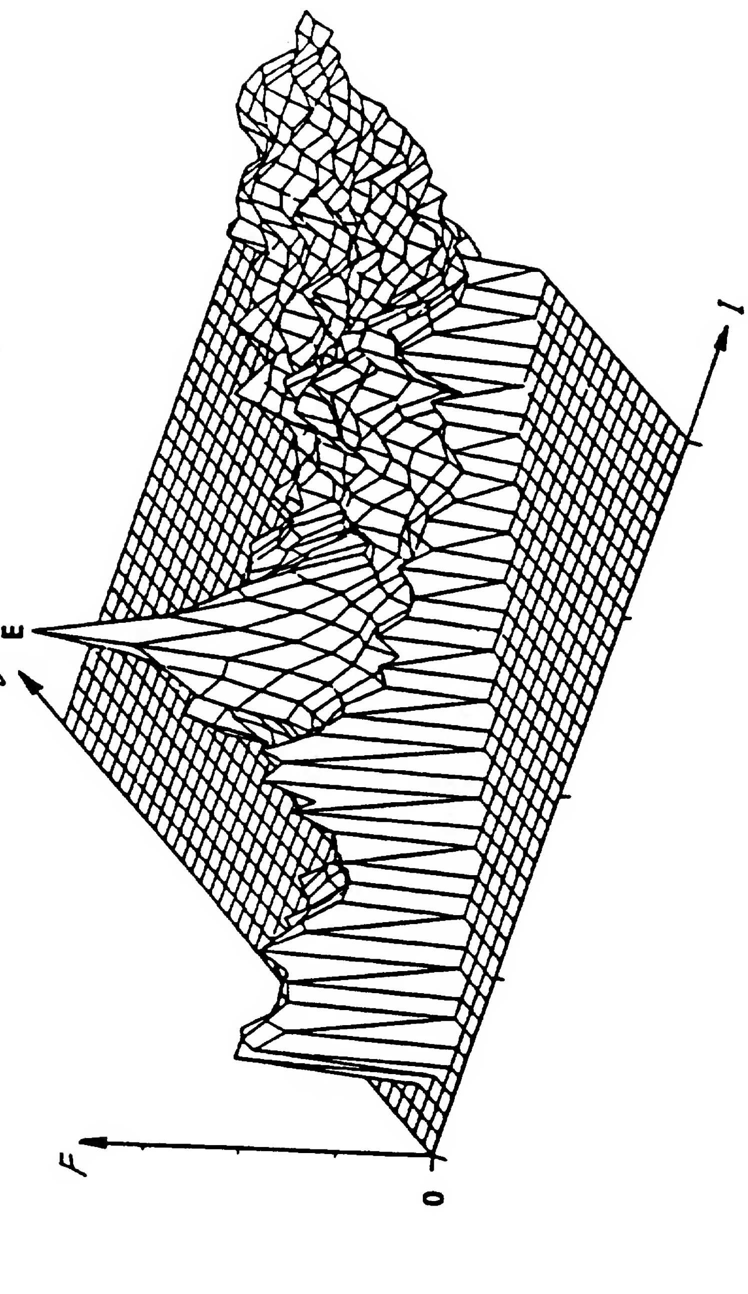

Fig.8D